ADAPTIVE CONTROL FOR ONE-DOF FINGER REHABILITATION ROBOT

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For my beloved mother and father

Siti Esah Binti Md Yassan and Jainal Abidin Bin Mohamed Nasir,

and especially to my beloved friend

Nur Amirah Binti Mohamad Husni

Thank you for your love, encouragement and support.

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ABSTRACT

This project presents one of an adaptive control technique to control the DC motor for one-DOF (Degree of Freedom) finger rehabilitation robot. Many different types of controllers are used to provide accurate positioning of the of the DC motor for the rehabilitation robot. One of the common used in controller system is proportional–integral–derivative controller (PID controller). However, the limitation of the PID controller is unable to adapt the variations in the load, as handgrip stiffness can be varied from patient to patient and PID controller is needed to tune for each stiffness. The performance of the robot will be affected and the steady state error occurred when the unknown and inaccessible load torque is imposed. Therefore, in this project, a Model Reference Adaptive Control (MRAC) is proposed to design a stable controller that able to cope with the variations handgrip stiffness to reduce the positioning error and steady state error. The simulated result show that the designed adaptive controller provides good response with reduced settling time and without steady state error for entire range of handgrip stiffness. The MRAC controller will perform better for rehabilitation robot that able to cope with patients without the aid of any additional stiffness detection sensors.

ABSTRAK

Projek ini berkenaan tentang salah satu *Adaptive Control* yang digunakan untuk mengawal DC motor bagi *one-DOF (Degree of Freedom)* pemulihan robot. Terdapt beberapa jenis pengawal yang digunakan untuk memdapatkan kedudukan DC motor dengan tepat bagi robot pemulihan. Salah satu sistem pengawal yang biasa digunakan ialah P*roportional–Integral–Derivative controller* (*PID Controller).* Walau bagaimanapun, *PID Controller* tidak dapat menyesuaikan kawalnya dengan pelbagai bebanan, ini kerana *handgrip stiffness* boleh diubah dari seorang pesakit kepada persakit yang lain dan *PID Controller* terhad kepada *standard handgrip stiffness* sahaja. Prestasi robot akan terjejas apabila *load torque* dikenakan kepada nilai yang tidak diketahui dan sistem yang tidak dapat diakses dan ia akan mempunyai *steady state error*. Oleh itu, didalam projek ini, *Model Reference Adaptive Control (MRAC)* direka untuk robot pemulihan bagi mengurangkan *steady state error* dan *controller* yang direka mampu mengatasi pelbagai jenis beban daripada *handgrip stiffness.* Hasil simulasi menunjukkan bahawa *adaptive control* yang direka memberikan performance yang baik dengan mengurangkan settling time dan tidak mempunyai steady state error untuk semua *handgrip stiffness*. *MRAC controller* dapat berfungsi dengan baik untuk robot pemulihan yang juga dapat membantu pesakit tanpa bantuan sebarang *stiffness detection sensor*.

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LIST OF SYMBOLS AND ABBREVIATIONS

K_b	–	Back emf constant
K_t	–	Torque constant
R	–	Resistance
H	–	Inductance
J	–	Moment of Inertia
b	–	Viscous friction constant
I_c	–	Max current
K_p	–	Proportional gain
K_i	–	Integral gain
K_d	–	Derivative gain
r	–	Input signal
y_m	–	Reference model output
y	–	Actual plant output
e	–	Error
u	–	Controller
θ_1, θ_2	–	Control parameters
γ	–	Adjustment gain
σ	–	Sigma
m	–	Coefficient of m
n	–	Coefficient of n

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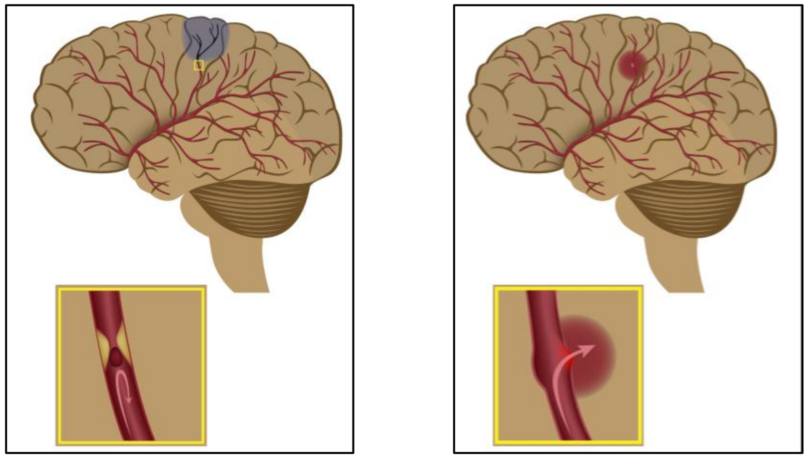
CHAPTER 1

INTRODUCTION

1.1 Stroke

Stroke is a type of brain injury depend the part of the brain that affected or disability of one side of the body such as trouble with moving, walking or thinking. Ischemic stroke happens when clot block the blood vessels that cause the lacking of the blood to flow to the brain, which reduce the oxygen in the brain [1]. In the artery wall, an atheroma known as fatty material breaks into small pieces that block the blood vessels and lead to stroke. Furthermore, if blood pressure drop rapidly, it can cause the patient lose consciousness and if the circulation of blood pressure is not recovered with proper medical care it can cause death [2].

Hemorrhagic stroke happens when the blood vessels burst, blood spread into the brain and cause damage [3]. An aneurysm is expanded the artery wall and it occurs when the blood pressure is dangerously high, which the artery wall become weak and swelling that cause the artery wall become thin and blood vessels burst. Some case happens when an arteriovenous malformation (AVM), a tangle of blood vessels in the brain pass through from arteries to the veins. The blood vessels can burst and cause the bleeding of the brain because of the cluster of abnormally formed blood vessels. When the blood flow in high pressure on the weak artery wall, it causes the AVM to stretch or bust [4]. In Figure 1.1, shows the overview of the type of stroke: ischemic stroke and hemorrhagic stroke.



(a) (b)

Figure 1.1: Type of Stroke; (a) Ischemic Stroke, (b) Hemorrhagic stroke [5]

In Malaysia, stroke is one of the top five of the major causes of death and causes of hospitalization in a government hospital. Since 2015, the percentages death causes of the stroke in the government hospital have ranged from 6.6% to 8.4% [6]. In Malaysia, males and females life expectancy at 72 and 76 years old, respectively. Based on disability of the stroke patients, such as paralyzed of one side of the body, moving and walking and stroke is one of the diseases with the greatest burden for the family. In Malaysia, the mean age of the stroke patients range is between 54.5 and 63.6 years and hypertension is the top factor for the stroke [7].

The effects of the stroke is lose disability of at least one hand and finger, which the stroke patients experiencing delays in gripping and releasing ability. The symptoms occur in the brain on the fine motor control which regulates movement through muscles, the skeleton and neurological messages [8]. Stroke often cause paralysis at hands and finger and at least paralysis on one side of the body. Stroke that occurs on one side of the brain will affect one side of the body, which right brain strokes will affect the left side of the body and left brain strokes will affect the right side of the body. Stroke patients relearn the use of fine motor skills will helps of hand and finger exercise, movement and physical therapy. The communications between the brain and affected area of stroke will happen when repeated exercises on the affected side of the body, hands and fingers [9].

1.2 Rehabilitation Program

Clinical Practice Guidelines for Management of Stroke state that stroke is a second major cause of death and health problem worldwide and stroke also leads on the disability report by World Health Organization (WHO) [10]. In Malaysia, South-East Asian Medical Information Centre (SEAMIC) data report that stroke is third major causes of death in the 1990s and fourth major cause in 2002 [11]. Millions of stroke survivors are still alive today and 30% of them recovery from any type of permanent disability [12]. As many of the therapies in the hospital used to help patients with recovery from disability and prevent the patients from the future stroke. From the stages of disability of the stroke patients will the determines the time of the patients need to spend in post-stroke rehabilitation [13]. In Figure 1.2 shows the Malaysian health facilities for Post-Stroke Care for the stroke patients. Specialist Clinics, district hospitals or at outpatient primary care are provided post-stroke care for the patients that discharged from hospital after acute stroke based on tertiary or state referral centre. In Malaysia, Family Medicine Specialists (FMS) and Malaysian Health facilities, primary care, secondary or tertiary are being provided with the stroke care spectrum [14].

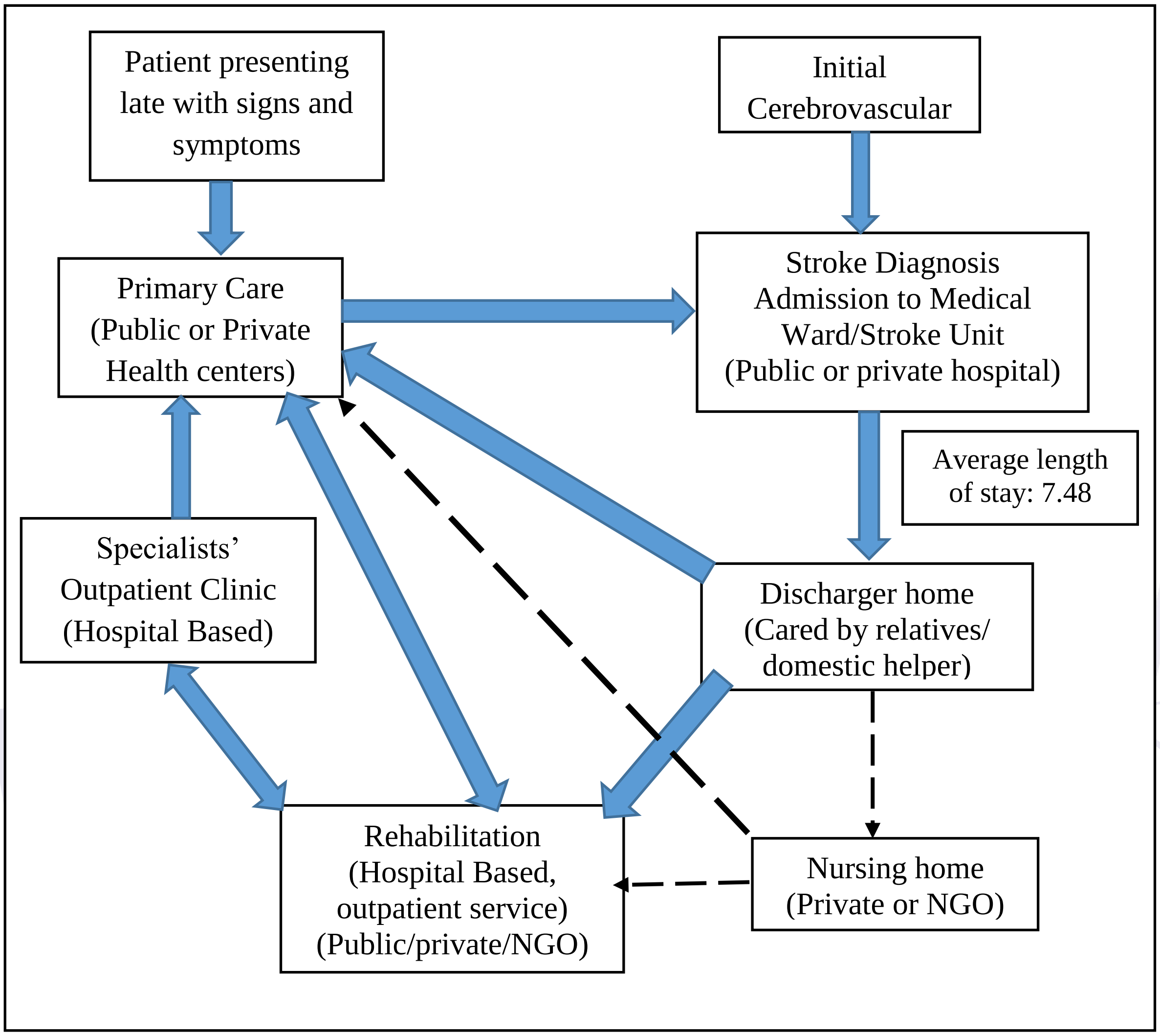


Figure 1.2: Malaysian Health Facilities for Post-Stroke Care [14]

1.3 Stroke Rehabilitation

Stroke rehabilitation one of treatment for the stroke patient that help the patient keep the ability and recovery the disability to move and self-care tasks such as eating, getting out the bed and walking [15]. National Stroke Association Malaysia (NASAM) state four types of stroke rehabilitation are physiotherapy, occupational therapy, speech therapy and counselling [16]. Generally, the two main types of stroke rehabilitation are physiotherapy and occupational therapy. Physiotherapy helps a patient learn to use arm and leg again and return to the highest possible level of physical function as balanced movement, increases the strength and stamina, and strengthening motor skills that conducted by the physiotherapist. Physiotherapist at the hospital will provide a detailed guideline to the patients to relearn and regain movement. Occupational therapy helps the patients to improve the performance of daily activities such as walking, eating, feeding and housework. The occupational therapist will help the patients the correct way to get up from bed, eat by itself, walk without increasing the stiffness and pain in the affected side of the body [16].

Options for stroke rehabilitation care can be categorized based on the hospital, community and institution. Hospital- based stroke rehabilitation includes outpatient care and daycare stroke rehabilitation facilities. Outpatient stroke rehabilitation is for the discharged patient for rehabilitation services provided by physiotherapists and occupational therapists. Daycare stroke rehabilitation where the patient spends part of the patient's day in the hospital. Institutional stroke rehabilitation care is given in nursing homes or homes for the elderly and community stroke rehabilitation care, which is usually provided by a team of physiotherapists and occupational therapists, with or without nursing staff and a social worker or psychologist [16].

1.4 Rehabilitation Robot

Rehabilitation robot, automated machine designed to improve the movement of patients with stroke with impaired physical function [17]. An example of an assistive robot is a Manus ARM (Assistive Robotic Manipulator) [18] that is mounted on a wheelchair with a robotic arm controlled by a chin switch or other input device. Therapy robots are machines that allow patients to exercise with the robot. An example of therapy robot is an MIT-Manus, which helped the stroke patients to reach the tabletop if the patients could not perform tasks by themselves [19]. For patients receiving additional therapy from the rehabilitator, the rate of their arm movement to recovery can be improved. In addition to the therapy robot, the Lokomat robot [20] is the robot used to support the weight of patients and moves the legs in a walking pattern over a moving treadmill. In Figure 1.3, show the example of rehabilitation robot, (a) MIT Manus robot and (b) Lokomat robot.

(a) (b)

Figure 1.3: Rehabilitation Robot; (a) MIT Manus robot [21], (b) Lokomat robot [22]

The main application of the rehabilitation robot is to help recover the disability of stroke patients through rehabilitation training and the rapidly increasing application of the rehabilitation robot [23]. By using a rehabilitation robot, the patients may perform training more frequently and longer duration of task practice. Various rehabilitation robots have been developed with different haptic modalities and consists of actuators commonly used by the DC motor to produce the desired movement of the end- effector holding the patient's limb for training. For the rehabilitation robot, different types of controllers are used to accurately position the motor for robots [24].

1.5 Control System

A control system is a system that directs or regulates the system's behaviour to achieve the desired results, which provides the desired response by controlling the output. The control system where the output is controlled by varying inputs and varies input with some mechanism. The control system can be classified as an open loop control system and a closed loop control system based on feedback path. Since the DC motor is used as an actuator in one-DOF robots, robots are usually developed without a reducer or gear to make them drivable backwards. It makes the main task of control part of the position control of the DC motor. Different types of control techniques have been applied to provide accurate DC motor control for the rehabilitation robot, and the most common controller with simple structure and easy implementation is PID controller. For the rehabilitation robot, different types of controllers are used to provide accurate positioning of the motor for robots. The details of the previous studies of the types of control of the rehabilitation robot were discussed in Chapter 2.

1.6 Problem Statement

Applications of rehabilitation robots increasing rapidly and becoming a common upper extremity rehabilitation because the robot able to provide intensive rehabilitation consistently for longer duration. Degree of freedom (DOF), one of classification of the rehabilitation robot. One-DOF rehabilitation robot can use at home without the aid of assistant or therapist and usually made only specific part of the body. Some robot with multiple DOF can used for the training of different part of the body and make the robot more complex and expensive.

For the controller part, different types of control techniques have been applied to provide accurate DC motor control for the rehabilitation robot, and the most commonly simple structure and easy implementation is the PID controller, which provides an accurate positioning of the motor for robots. However, limitation of PID controller is not able to adapt the variations in the load, from patient to patient, stiffness can be varied and PID controller tuned for standard stiffness. Whenever the unknown load torque is applied, the performance of the robot will be affected by the steady state error.

1.7 Objectives of project

The main objectives of this project are to develop one-DOF of finger rehabilitation robot with adaptive control of the DC motor. The objectives are as follows:

I. To design the Model Reference Adaptive Control controller of one-DOF finger rehabilitation robot of DC motor.
II. To design the PID controller of one-DOF finger rehabilitation robot of DC motor.
III. To compare the performance of DC motor between the Model Reference Adaptive Control controller and PID Controller.

1.8 Project Scopes

This project based on the simulation using MATLAB and in order to achieve the objective, the scopes of this project are:

I. The controller of the DC motor of the rehabilitation robot is available for the handgrip stiffness.

II. The mean handgrip stiffness that used for this project are 0.5541 ± 0.454 Nm/rad.

III. Model Reference Adaptive Control is used for the controller part and only focus for the Lyapunov Method.

IV. The PID controller, adjustment mechanism, θ, and sigma, σ, are tune manually until get the desired output response.

V. Simulation of the output no accurate or ± 0.5 because of the hardware of DC motor or other component run in the real time simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the evaluation report on the information found in the literature relating to the rehabilitation robot controller and this chapter should describe summaries, evaluate and clarify this literature. In a literature review, all the information and steps to be taken are briefly explained. All raw materials and components will be specified and analyzed, so that the project development process can be run smoothly. There are several case studies from the previous project also studied to improve understanding and theory of the project.

2.2 Rehabilitation Robot

Rehabilitation process or robot used for improving the functional movement for the post-stroke patients are there for highly required. Rehabilitation robots can be classified according to the degree of freedom (DOF) [25]. In specific, DOF is defined modes in which system or mechanical part can move. The total number of aspects of motion or movement is equal to the number of DOF. If the amount of DOF increase, the robot will become more complex and expensive. The rehabilitation process for the handgrip, one-DOF are suitable because robot simpler, less expensive and affordable which can operate without the aid of assistant or therapist.

(a) (b)

Figure 2.1: Hand Rehabilitation Robot; (a) Hand-Wrist Assisting Robotic Device [26], (b) Armeo Boom or Armeo Spring [27]

In Figure 2.1 shows the Hand-Wrist Assisting Robotic Device (HOWARD) [28] and Armeo Boom or Armeo Spring [29] are robotic therapy device use for stroke patients to regain the disability of their hands. HOWARD wraps around the hand and connect with a computer program that used to direct patients through a physical therapy session. HOWARD only monitors the hand movement and provide assistance to complete each activity, but the user initial hand movement from the patients itself [30]. Armeo Boom or Armeo Spring therapeutic technologies combine self-directed movement exercises with Augmented Performance Feedback to increase range of motion, strength and endurance. Armeo Boom is sophisticated device that can be programmed for each patient, guide the user through repeated, precise movements and provide real-time feedback of each patient [29].

2.3 Types of Controller

Since DC motor used as an actuator in one-DOF that convert electrical energy into mechanical energy and provide continuous movement and speed of rotation can easily to control [31]. The robot is developed without a reducer or gear to make it dribble back and the main control task is used to control the position of the motor. Many advanced techniques have been applied to the position control of the DC motor, since the DC motor has variations in its parameters during operation and its response is also sensitive to load variations. Sometimes conventional feedback controls can't work well to cope with changes that vary with their dynamic system [32]. The transient response of the system to be less precise and accurate to the desired stable state is caused by the nonlinear system and receives many disturbances.

Samadhi Manasa [33] was developed a Proportional-Integral-Derivative controller (PID Controller) to control the position of the DC motor that implemented on the ARM Cortex M3 microcontroller. The PID controller used to reduce the steady state error between the measured position and the desired position by calculating the error and the modulated voltage of the output that used to adjust the position DC motor accordingly. By adding and integrating the PID controller to the system, the system becomes a closed system which able the system to reduce the steady state error and control the position of the DC motor to desired point. The PID controller helps to get the output in the short time with the minimal oversight and reduce the steady state error.

Smeeta C. Maheriya, Hardik V. Kannad [34] was developed a position control of Brushed DC motor using PID controller in MATLAB. In this project, the gain of the PID controller is obtained by tune manually or trial and error method, Ziegler-Nicholas Tuning Method and Good Gain method. The main aim of this project is to reduce steady state error, settling time and overshoot. The simulation result shows that the Good Gain method more stable then the Ziegler-Nicholas Tuning Method. The PID controller will performance better and allows the system to reach the mean position faster, without overshoot and steady state error.

Position control of the DC motor based on Model Reference Adaptive Control (MRAC). Mohammet Koksal [35] was developed a Model Reference Adaptive Control (MRAC) of the position control for DC motor. The design of the controller based on the poor performance of a DC motor or vary during normal operation or condition. This paper proposed to control the position of DC motor without requiring fixed motor parameters. This method aims to realize an MRAC for a plant that has a single input single output and without Finite Transmission Zeros (FTZ). This method adjusts feedback gains of the states and feed forward gain of the closed loop plant and equalizes its transfer function to the model. If the plant dynamic of DC motor can be expressed by the lower order of transfer function, reference model can be chosen as lower order. This method needs modifications to use with other plants.

Munadi, M. Amirullah Akbar [36] have designed a Model Reference Adaptive MIT rule and control law control system with PID controller. This control system can affect the response of the adaptive control system and match the desired ideal response from the reference model even when the system is disturbed. The Model Reference Adaptive Control (MRAC) is included in the reference model, adaptation mechanism, plant and control law. The ideal response for the reference model is based on the modelling of the dynamic DC motor and DC motor plant using Simscape in Simulink. The DC motor controller must be able to adapt to the environmental conditions and maintain system performance without a steady state error. This study used MRAC with the MIT rule method for the adaptation mechanism and estimated the controller parameter to match the reference model. The purpose of this study was to design the system dynamics to obtain the solution modelling without complex mathematical equation. The results showed that the adaptive control system was stable and resistant to varying disturbances using the MIT rule.

Junaid Zahid *et.al.* [37] was developed a controller of the DC motor for one-DOF rehabilitation robot using the Model Reference Adaptive Control (MRAC). In this project, Model Reference Adaptive control was designed to reduce the positioning error of the robot and able to cope with variations in limb stiffness of the stroke patients. The limb stiffness that are used in this paper are for the wrist stiffness only. The mean wrist stiffness of the movement are included toward flexion, toward extension, toward radial deviation, toward pronation and toward supination. From the mathematical model of the DC motor, the MRAC is designed in the Matlab by using Simulink and use as a reference model in MRAC. PID controller is low adaptability to external disturbance or load and the PID controller is tuned based on a set standard wrist limb stiffness. In this paper, the comparison between the PID controller and MRAC be made to compare the settling time, rise time, steady state error.

2.4 Finger Joint Stiffness

The failure of one side of the brain can affect the way of the stroke patients' muscles work. Brain sends signals through nerves to the muscles to make muscles move. The swollen hand can happen when the stroke patients' not moving the hand and unable to move it. The swelling may happen because fluid builds up in the tissue if the muscles are not moving around. One of the causes of finger joint stiffness is the tightness of the muscles that contained within the region in hand. Stiffness is the reduction of the range of the movement which difficult to bend or straightening the finger joint and it can lack of the flow within the range of the movement. The metacarpophalangeal (MCP) joint in the finger joint connects the metacarpal bones to the proximal phalanges of the digits and responsible for the wide range of the movement, that including flexion and extension.

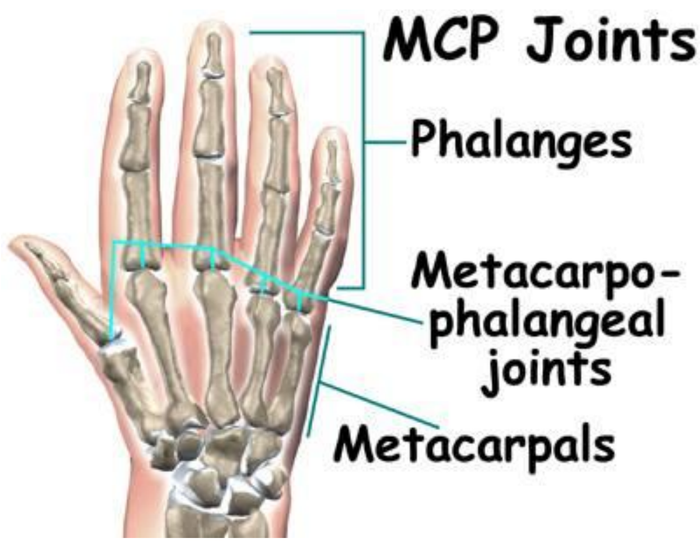


Figure 2.2: Metacarpophalangeal Joint in Hand [38]

DG Kamper *et.al.* [39] have develop a biomechanical simulation of the extrinsic flexor muscles on the finger joint flexion of the damping and passive stiffness. By experimentally in human subjects, the passive resistance to flexion/extension movements were determined of each of the joints. In this experiment, six healthy adults were participated and left index finger was used for each subject. In order to maintain wrist position and orientation, the wrist was placed in fiberglass cast that was clamped to a table. These operating points were spaced 10^0 apart, ranging from 10^0 the of extension to 60^0 of flexion. From this paper, both stiffness and damping increased in joint diameter in the

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